Procedure: C-A-AGS-579-G2
Revision: 02
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Title: g-2 Experiment EMS Process Assessment

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Approvals

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BROOKHAVEN NATIONAL LABORATORY
PROCESS ASSESSMENT FORM

I. General Information

Process ID:	AGS-579-G2			
Process Name:	g-2 Experiment			
Process Flow Diagrams:	AGS-579-G2-01, AGS-579-G2-02			
Process Description:	This process assessment covers the g-2 experiment at the C-AD. The g-2 experiment is designed to measure the anomalous magnetic moment of the muon. This is a fundamental measurement to test the Standard Model of particle physics. The experiment relies on a 15-meter diameter storage ring magnet, the world's largest single superconducting magnet. The experimental setup is used to store muons produced at an external target station using protons supplied by the AGS. Applicable Subject Areas include, Storage and Transfer of Hazardous Materials, Radioactive Waste Management, Pollution Prevention/Waste Minimization.			
Dept./Div.:	Collider-Accelerator Department			
Dept. Code:	C-AD			
Building(s):	V-target cave, 919			
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II. Detailed Process Descriptions and Waste Determination

The g-2 experiment at the C-AD is designed to measure the anomalous magnetic moment of the muon, a more massive sibling of the electron. This is a fundamental measurement to test the Standard Model of particle physics. The experiment is designed to make a measurement to extremely high accuracy, 3 parts per 10 million, where the smallest deviation from the Standard Model prediction would be an indicator of new phenomena. The experiment relies on a 15-meter diameter storage ring magnet, the world's largest single superconducting magnet, with a field uniformity of 1 part per million and a stability of 1 part per 10 million. The experimental setup is used to store muons produced at an external target station using 24 giga electron volt (GeV) protons from the AGS. As the muons decay, detectors that are distributed uniformly around the circumference of the storage ring measure their spin direction. Physically, the g-2 experiment is comprised of static experimental hardware made up of beam lines, magnets, power supplies and associated cooling water loops. A schematic of the g-2 experiment is shown in diagram AGS-579-G2-01.

The AGS supplies protons that are directed down the ‘V1’ beam line to a nickel target known as the ‘V-target’. A cascade of secondary particles is produced when protons strike this target. Particles of interest, muons and pions, are magnetically guided inside vacuum-beam tubes to Building 919 that houses the g-2 superconducting storage ring. Unwanted particles emerging from the V-target are allowed to deposit their energy into an iron beam stop.

When a high-energy charged particle, such as a proton, leaves the vacuum confine of an accelerator or a beam transport line, it encounters various materials along its flight path. These materials, which are used in the magnetic transport components, vacuum pipes, cooling system, tunnel environment and radiation protection shielding include various metals such as aluminum, copper and steel, as well as air, water, concrete and soil. When a high-energy proton interacts with an atomic nucleus in its path, other particles such as neutrons, other protons and nuclear fragments may be produced, converting the struck nucleus to a smaller nucleus. As many as 50 nuclei may be broken up by these "spallation reactions" when dissipating the energy carried by a single 24 GeV proton. A common fragment produced in most spallation reactions is tritium. The amount of tritium present at any given time will depend upon tritium's half-life and the time since production of the tritium has ceased. There are many other fragments that are also radioactive; however, most are very short-lived (minutes to days).

The soil radiation-shield and the cooling water for magnetic transport components are the two sources of radionuclides that can have the most significant impact upon the local environment. The most significant radionuclide produced in cooling water as far as the environment is concerned is tritium (half-life = 12.3 years). There are other short-lived radionuclides (half-lives of 1.2 to 20 minutes) produced by spallation of the atoms that compose water. These short-lived radionuclides are oxygen-14, oxygen-15, nitrogen-13 and carbon-11. These radionuclides decay so rapidly that they have no impact upon the local environment. In soil, the significant radionuclides produced are tritium and sodium-22, which has a half-life of 2.6 years. A diagram showing process inputs and outputs is shown in AGS-579-G2-02.

Regulatory Determination of Process Outputs

1.0 Cooling Water Systems Systems Drained and Tritiated Water Removed

The g-2 cooling water system consists of a primary closed loop, a heat exchanger and a secondary, non-contact open system with a cooling tower (refer to process flow diagram AGS-004-CWS-20). Heat from g-2 magnets and the V-target (via a dedicated heat exchanger) is transferred to the primary loop water. The primary loop rejects its heat load to the secondary loop via another heat exchanger. The secondary loop then rejects its heat to the atmosphere via an open cooling tower. The primary loop contains activated water due to exposure to the beam. Make-up water for the cooling systems is supplied by the BNL potable water system. Biocide and other water treatment chemicals are added to the g-2 cooling tower system prior to entering the cooling tower. Cooling tower blowdown and cleaning water is discharged to the storm system (outfall 006B, recharge basin HTe) (1.1). Water vapor from the cooling tower is released to ambient air (1.2). The g-2 cooling system has a make-up water deionizer and polishing filter/deionizer loop that bypasses the heat load. The water is deionized to reduce conductivity, which can create unwanted problems in the presence of intense magnetic fields. The make-up deionizer resin is sent off-site for regeneration and then returned to BNL for reuse (1.4). The spent polishing filter and deionizer resin is sent off-site for disposal as low-level radioactive waste approximately every 1 to 2 years (1.3, 1.5).

The g-2 beam line primary cooling system originally had a single 1,500-gallon water loop serving the 'V' and 'V1' beamline magnets and the Building 921 power supplies. This water contained high concentrations of tritium due to interactions with secondary radiation generated by the beam. This loop has since been divided to minimize the volume of water, which contains these high concentrations. In December of 1999, the 'V1' beam line cooling system was separated from the 'V' line cooling system. Total size for the highly tritiated water was reduced from 1,500 gallons to about 350 gallons. Also, the power supplies in Building 921 were taken out of the primary loop and are now cooled by a stand-alone air-cooled chiller system. There are no floor drains in the V-target area and the cooling water-system piping is completely contained within the concrete target hall and the transfer line tunnel. Floor drains are connected to the site-sanitary system in the transfer line tunnel.

The primary cooling water loop is now drained on a regular basis and the activated water is collected in the C-A tanker trailer and processed through evaporation (1.6). This new procedure mirrors the pollution prevention recommendation made in AGS-004-CWS. The exact drain-and-replace schedule is based on sampling results that show the speed of build-up.

Waste ID	Waste Description	Determination/Basis	Waste Handling	Corrective Action Required
1.1	Cooling tower blowdown and cleaning water (w/biocide)	Non-hazardous/ non-radioactive effluent as determined by process knowledge	Wastewater is discharged to the storm system (outfall 006B, recharge basin HTe)	None
1.2	Water vapor emissions from cooling tower	Non-radioactive / process knowledge	Vapors are released to ambient air.	None
1.3	Polishing bag filters	Non-hazardous/ radioactive solid waste as determined by process knowledge/ radioactivity survey	Waste is sent off-site for disposal as low level radioactive waste	None
1.4	Make-up deionizer resin	Non-hazardous/ non-radioactive solid waste as determined by process knowledge	Resin is sent off-site for regeneration and then returned for reuse	None
1.5	Polishing deionizer resin	Non-hazardous/ radioactive solid waste as determined by process knowledge/ radioactivity survey	Waste is sent off-site for disposal as low level radioactive waste	None
1.6	Activated cooling water	Radioactive / process knowledge, direct analysis	Water is collected in the C-A tanker trailer and processed by evaporation	None

2.0 Activated **Soils / Groundwater Impacts**

There are two primary mechanisms by which g-2 operations can have an impact on soils and groundwater in the immediate vicinity of the target cave: (1) soil activation by secondary radiation produced by beam striking the V-target, and (2) soil activation caused by secondary radiation produced by unintended beam losses in focusing magnets. Groundwater can be impacted only if rainwater is allowed to pass through activated soils, thereby leaching radionuclides downward through the unsaturated zone to the water table. In anticipation of the expected creation of radionuclides in the beam stop area, a concrete cap was constructed directly above it in June 1998 to prevent rainwater infiltration through activated soil volumes. The cap, constructed of gunnite cement coated with a reinforced emulsion waterproofing, extends over the entire beam stop.

Figure 1 g-2 beam-stop soil cap.

The goal of the C-AD MCR operators is to provide protons "on-target", without losses that occur due to incorrect beam positioning. Efforts made to ensure that the beam is on-target is referred to as beam tuning. If the beam is improperly tuned, it may strike quadropole magnets or other metal components used to guide the protons along the intended path. If the beam is out of position to only a slight degree, a magnet may absorb unintended beam energy. When this happens, a cascade of secondary particles is produced which are capable of creating radionuclides in surrounding materials. Based on radiation area monitor readings obtained during runs of the g-2 experiment in 1998, it appears as if this type of beam loss was occurring at a quadropole magnet in the g-2 target cave identified as 'VQ12'. VQ12 is the last quadropole that the beam passes through before interacting with the target. Evidence for beam loss during the 1998 run is further strengthened by radionuclide concentrations seen in primary cooling water which were higher than those observed during earlier runs.

The shower of particles created by proton beam losses is strongly biased in the forward direction, relative to the beam. However, a certain percentage of secondaries are also scattered in the reverse direction, leading to soil activation around the 'V' transport line, adjacent to and south of the target cave. All such interactions occurred underground. Originally, the land surface above this area was not covered by a waterproof barrier. Consequently, tritium and sodium-22 have leached into groundwater resulting in radionuclide concentrations downgradient of the target cave that exceed federal drinking water standards. Several steps have been taken to mitigate this situation including new beam position monitoring and additional capping (see Section III for details). An Engineering Evaluation/Cost Assessment was undertaken to evaluate the treatment for the groundwater contamination, and will be completed in September 2002.

Waste ID	Waste Description	Determination/Basis	Waste Handling	Corrective Action Required
2.1	Tritium and Sodium-22 production in soil	Radionuclide type and quantity based on computer modeling	None	None

3.0 Airborne Radionuclide Production

In addition to the materials listed above, activation also takes place within the immediately surrounding air as the proton beam leaves the confines of the vacuum system and crosses an air gap to reach the target. Based on calculations from the CASIM (Cascade Simulation) Monte Carlo computer model, typical air activation products generated include argon-41, sulfer-35, phosphorus-32, sodium-22, oxygen-14, nitrogen-13, carbon-11, beryllium-7, and tritium (3.1). Most are short-lived with half-lives on the order of minutes and have maximum predicted production rates which range from microcuries to millicuries annually.

As a result of exposure to the beam, the nickel target will also become activated. The target is enclosed inside a stainless steel containment box about three cubic feet in size. The box is air-filled and experiences an average displacement of 4 liters per minute. This provides a hold-up of about 15 minutes for radioactive decay. The displaced air moves through polyester, HEPA and charcoal filters. Once the target is no longer needed, these filters will be disposed of as low-level radioactive waste (LLRW) (3.2). The majority of the produced radionuclides will remain fixed in the target. However, some gaseous radionuclides escape the confinement box. Those that have been observed in air samples taken near the target box include chlorine-38, chlorine-39, carbon-11, sodium-24, beryllium-7, manganese-28, scandium-44 and manganese-56.

Since the target is in an unmanned area, there is no forced air ventilation in the cave. Radiogases produced by the mechanisms described above are contained by the following barriers: (1) filters (in the case of the target), (2) an inner cave, and (3) an outer cave, which is itself sealed from the outside atmosphere by (4) a vestibule containing two sequential entry doors. Therefore, no atmospheric emission of radionuclides is reasonably anticipated from this source.

Waste ID	Waste Description	Determination/Basis	Waste Handling	Corrective Action Required
3.1	Airborne radionuclides from air activation and target irradiation	Radioactive / process knowledge, direct analysis	Airborne radionuclides are allowed to decay inside the target cave.	None
3.2	Spent polyester, HEPA and charcoal filters	Radioactive / process knowledge	To be disposed of as LLRW at the conclusion of the experiment	None

4.0 V-Target and Beamline Components

As discussed in the above section, the nickel target (see Figure 2) becomes activated as a result of exposure to the beam. At the end of an experimental run, targets are radiologically "hot" and exhibit very high exposure rates at contact. When the target reaches the end of its useful life, it will be shielded in place behind a thick wall of steel. Area radiation surveys will be performed when personnel entry is required. The target will remain shielded for several years until radionuclide activity has decayed to the point that exposure rates are reduced to less than 1 R/hr. When the source reaches this intensity level it will be placed by C-AD personnel in the center of a low-level radioactive waste shipment container for disposal at the Hanford site (4.1). The V-target is likely to be disposed of in this fashion within the next 10 years. At some future date, the entire beamline may be disassembled. This will generate several classes of used equipment including magnets, beam pipe, cables, and shield block. Magnet steel is recycled (4.2). If the coils are still usable, these will be recycled as well (4.2). Beam pipe and cable is disposed of as LLRW (4.3). Shield blocks are saved for re-use elsewhere within the C-A complex (4.2). Typically, physical decommissioning only occurs when there is a new experiment to occupy the space of an old one, otherwise the old equipment is left to decay in place.

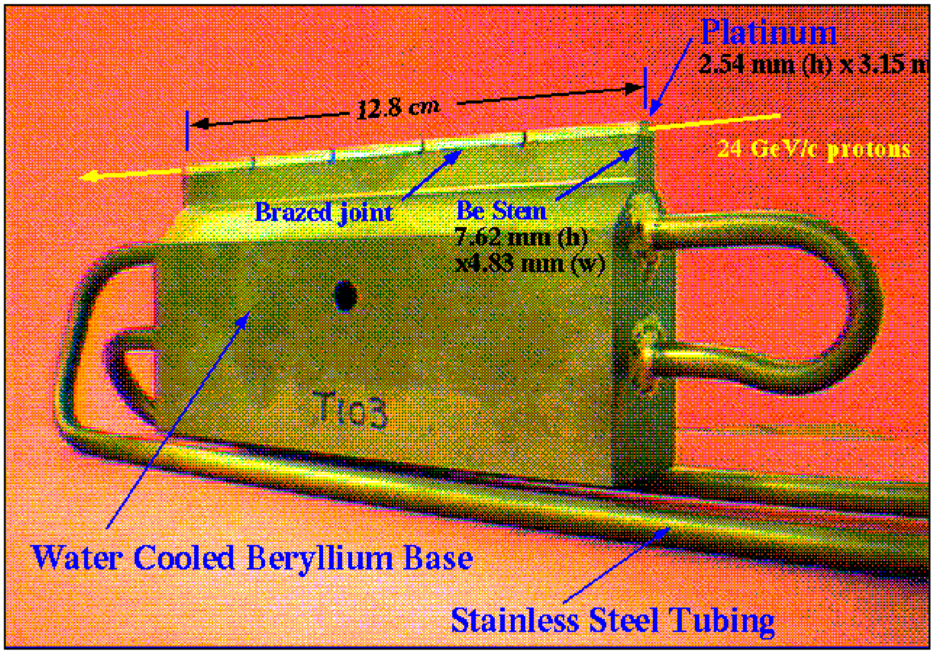

Figure 2 Example AGS target for A, B, C, or D lines.

Waste ID	Waste Description	Determination/Basis	Waste Handling	Corrective Action Required
4.1	V-target	Radioactive / process knowledge	Decay in storage, followed by disposal as LLRW	None
4.2	Used magnet steel, magnet coils, shield blocks	Radioactive / process knowledge	Reused at other locations within the C-A complex	None

Waste ID	Waste Description	Determination/Basis	Waste Handling	Corrective Action Required
4.3	Used beam pipe and cable	Radioactive / process knowledge	To be disposed of as LLRW at the time of decommissioning / disassembly	None

III. Waste Minimization, Opportunities for Pollution Prevention

During the initial effort of baselining the Collider-Accelerator Department processes for Pollution Prevention and Waste Minimization Opportunities each waste, effluent, and emission was evaluated to determine if there were opportunities to reduce either the volume or toxicity of the waste stream. Consideration was given to substitute raw materials with less toxic or less hazardous materials, process changes, reuse or recycling of materials and/or wastes, and other initiatives. These actions are documented in this section of the original process evaluation. Action taken on each of the Pollution Prevention and Waste Minimization items identified can be found in the Environmental Services Division's PEP 2000 Database. Further identification of Pollution Prevention and Waste Minimization Opportunities will be made during an annual assessment of C-A processes. If any Pollution Prevention and Waste Minimization Opportunities are identified they will be forwarded to the Environmental Services Division for tracking through the PEP Database.

IV. Assessment, Prevention and Control

During the initial effort of baselining the Collider-Accelerator Department Assessment, Prevention, and Control (APC) Measures operations, experiments, and waste that have the potential for equipment malfunction, deterioration, or operator error, and discharges or emissions that may cause or lead to releases of hazardous waste or pollutants to the environment or that potentially pose a threat to human health or the environment were described. A thorough assessment of these operations was made to determine: if engineering controls were needed to control hazards; where documented standard operating procedures needed to be developed; where routine, objective, self-inspections by department supervision and trained staff needed to be conducted and documented; and where any other vulnerability needed to be further evaluated. These actions are documented in this section of the original process evaluation. Action taken on each of the Assessment, Prevention and Control Measures can be found in the Environmental Services Division's PEP 2000 Database. Further identification of Assessment, Prevention and Control Measures will be made during an annual assessment of C-A processes. If any Assessment, Prevention and Control Measures are identified they will be forwarded to the Environmental Services Division for tracking through the PEP Database.